

The “Other” Energy in Buildings: Wireless Power Metering of Plug-in Devices

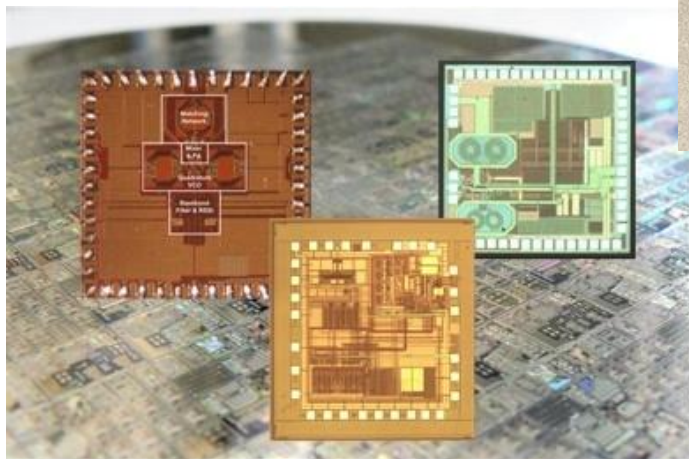
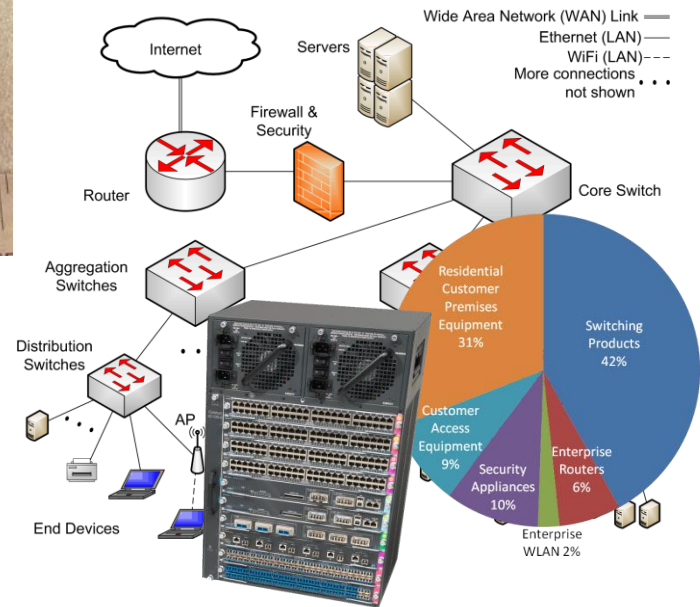
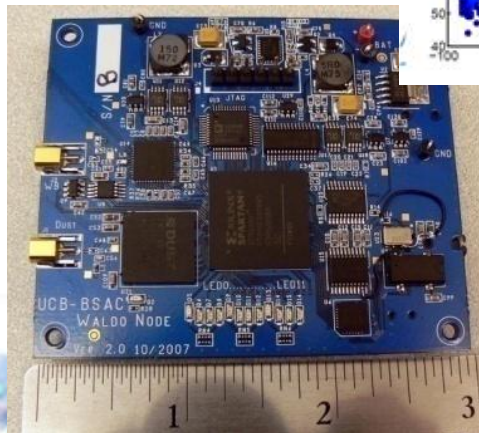
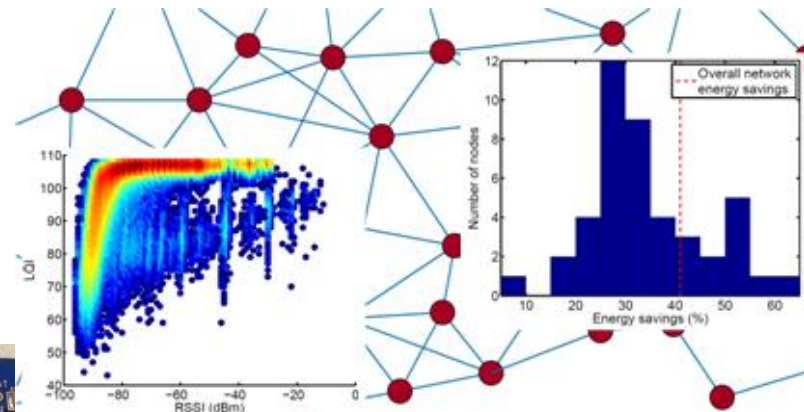
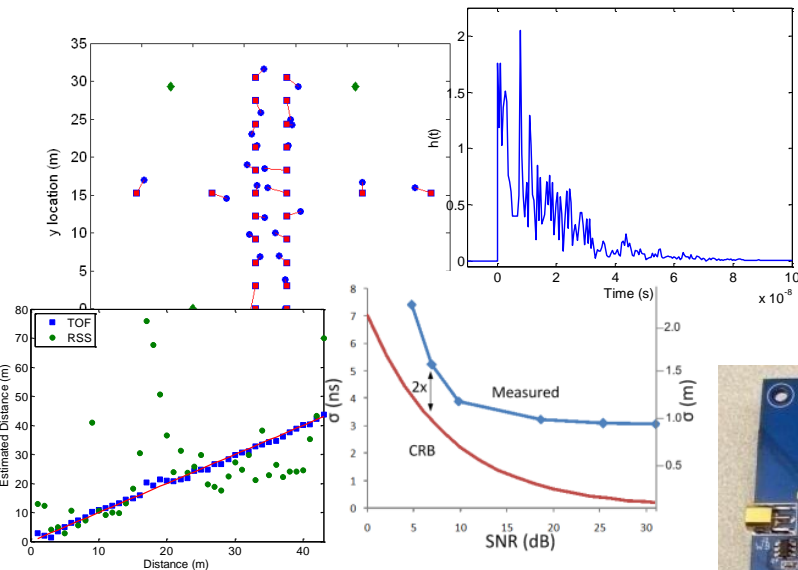
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17 June 2011



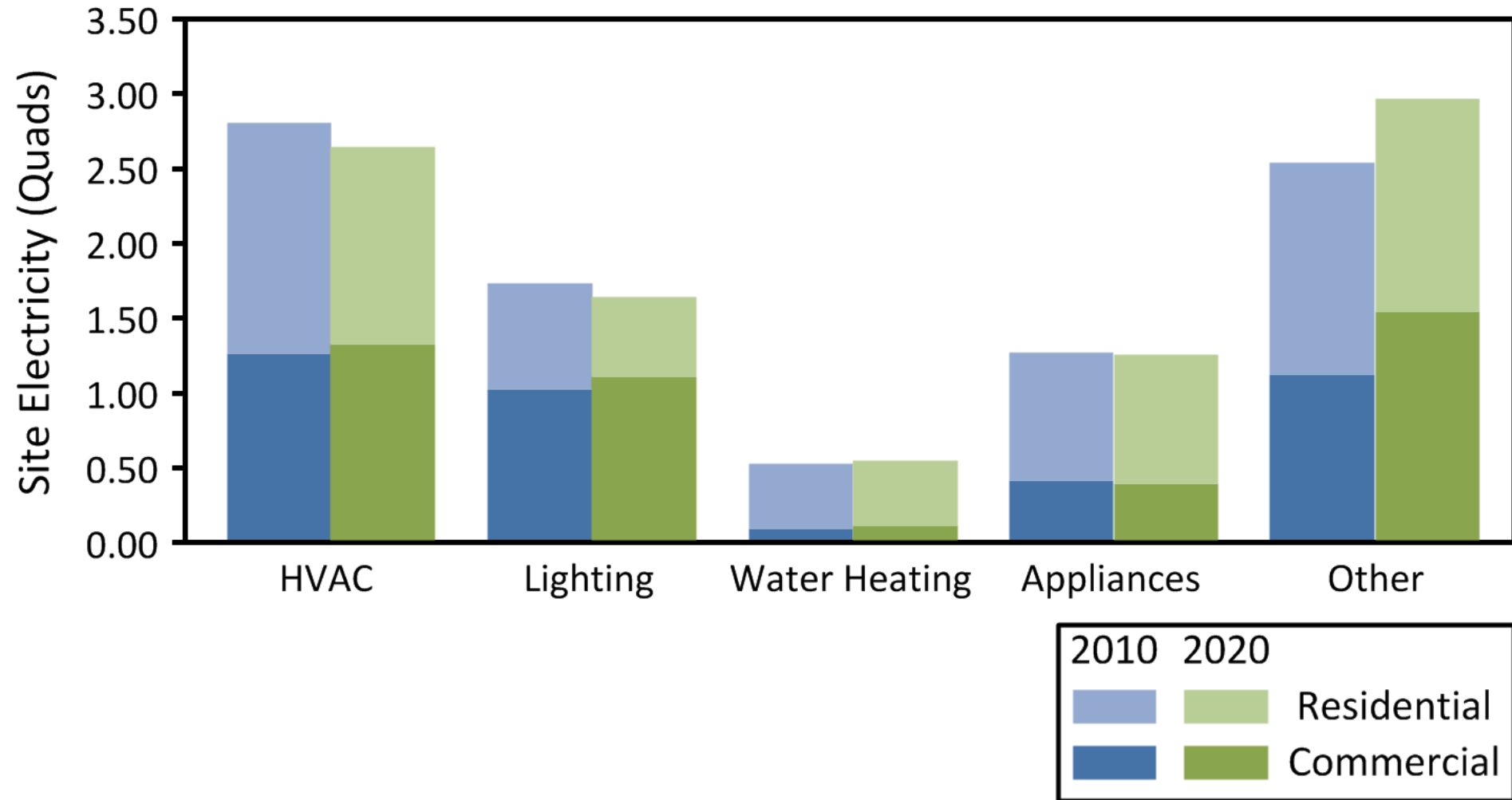
Previous Research

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Overview

- Motivation & Background
- Research Overview & Methodological Findings
- Example Energy Data Analyses
- Next Steps

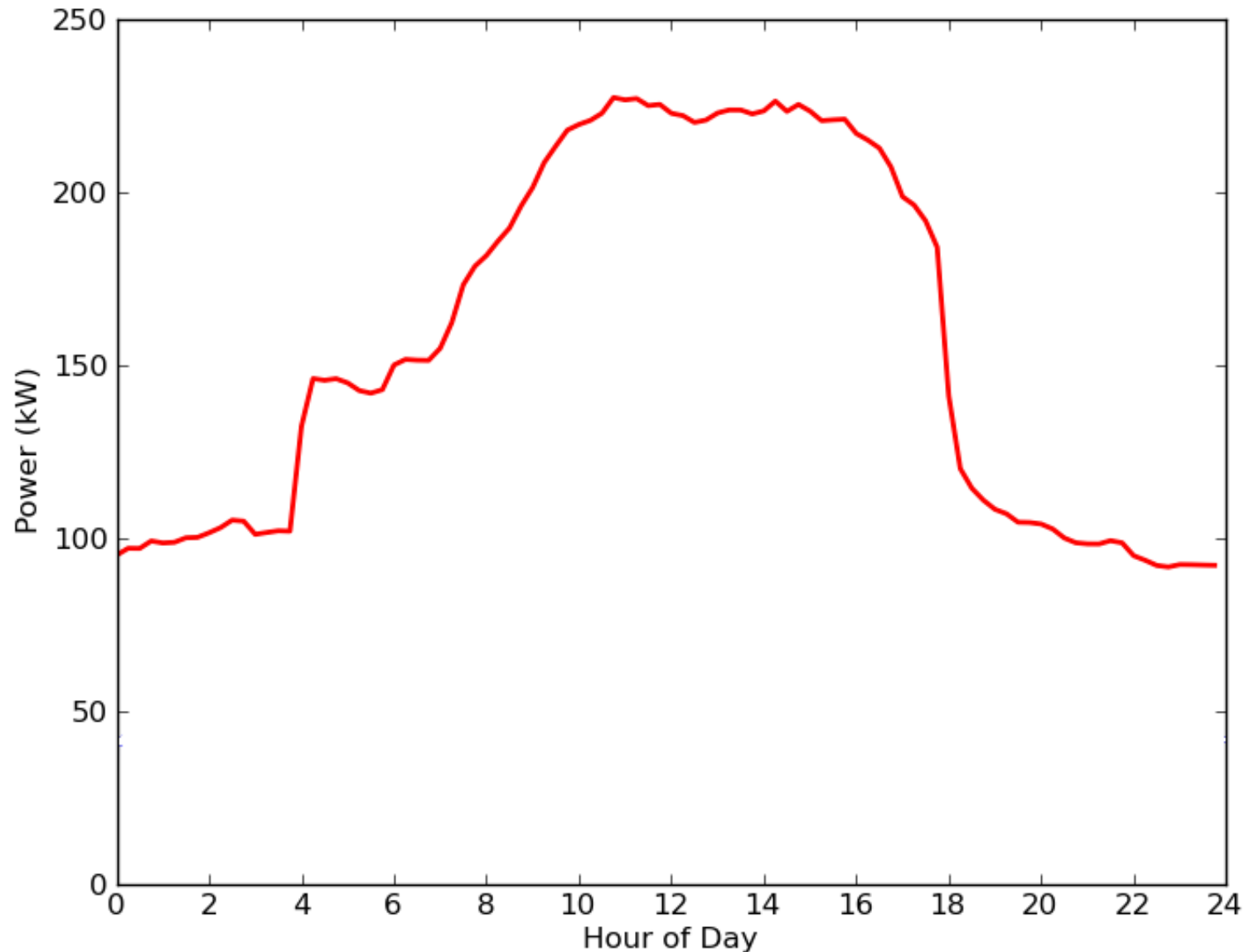
US Building Electricity Use Estimates



What's the "Other?"



B90 Average Weekday Electricity Load Shape



Existing Work

- Work at LBNL over the last 25 years
- National Estimates: CBECS and RECS
 - Include computers, electronics, other
 - Large uncertainties
- Metering Studies
 - ECW Residential Metering (2010)
 - 50 homes, 1 month, 16 devices per home, 6 min samples
 - ECOS CA Office Plug Loads (2008)
 - 450 devices across 50 buildings, 2 weeks of data
 - Short duration, few devices...

Research Problem

The problem: Cost, complexity prohibits scale and long metering periods

Use new information technology to mitigate the problem:

- **Improve field techniques**
- **Data collection with wireless meters**
- **Automated analysis for large data sets**

Enable plug-in field studies capable of filling key data gaps.

Overview

- Background
- Research Overview & Methodological Findings
 - Goals
 - Field Sites
 - Taxonomy & Inventory
 - Meter development
 - Network deployment
- Example Energy Data Analyses
- Next Steps

Research Goals

- Leverage wireless sensor technology to enable a new class of field studies
- Develop methods to accurately describe energy use of plug-in devices at the:
 - Whole-building level
 - Device category level
 - Individual device level
- Test methods in a small sample of homes and commercial buildings

Field Test Buildings

- LBNL Building 90
 - 90,000 s.f.,
450 regular occupants
 - Typical office building
- Stanford Hospital
- 2 East Bay homes
- 1 low-energy home in Boston area



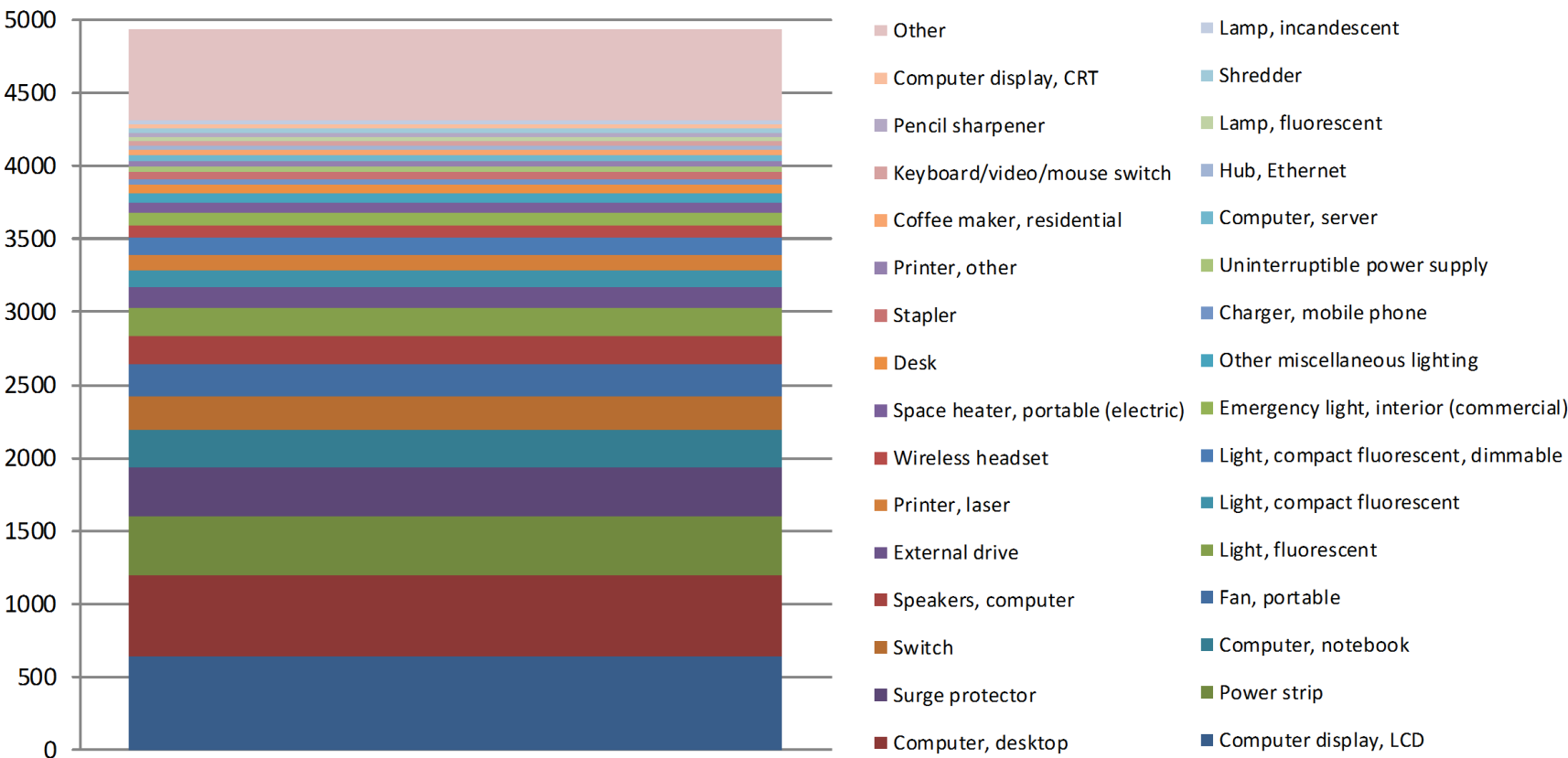
Taxonomy of Devices

Electronics	Miscellaneous	Traditional
Audio		
Cash Exchange		
Computer	Computer, desktop	
Display	Computer, integrated CRT	
Imaging	Computer, integrated LCD	
Networking	Computer, notebook	
Peripherals	Computer, server	
Security	Computer, tablet	
Set-top	Dock, notebook	
Telephony	Dock, tablet	
Video	Other computer	

Inventory Methods

- Cataloging a large number of devices is time consuming
- Tested four methods
 - Voice recognition
 - Hand written with transcription
 - Video with transcription
 - Direct entry into laptop with auto completion
- Direct entry selected
 - Ensures user conforms to taxonomy and records required information
 - 100-150 devices per hour for a two person team

B90 Inventory Results



- Smallest category shown is 0.5% of total number of devices.
- 127 device types in “Other”
- Inventoried 98% of building floor area.

Metering Requirements

- Automated data collection
- Compact enough for dense metering
- Accuracy comparable to standard meters
- Data reported back to data store at LBNL
- Low-cost

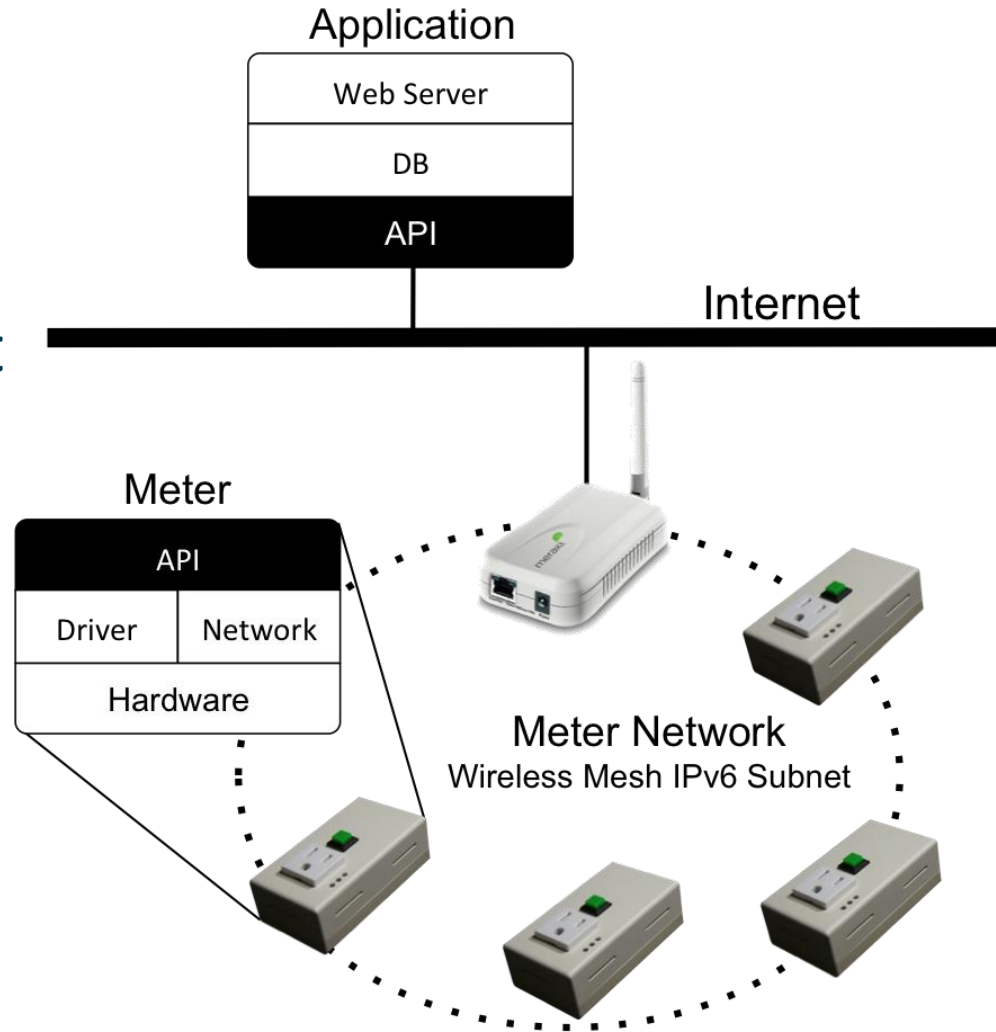
Evolution of Plug-in Metering



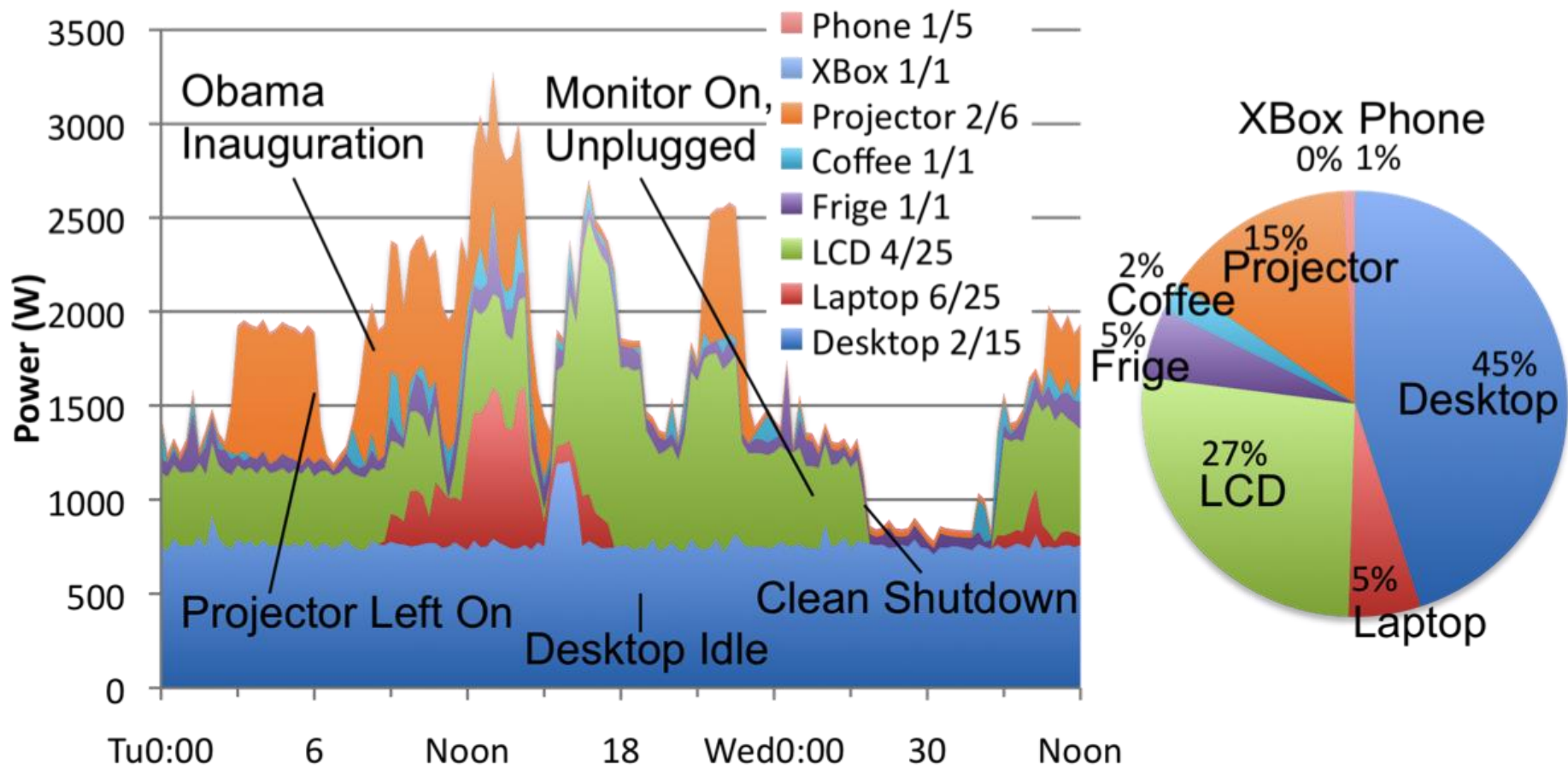
201000:
Wattstop Line Meter
Wireless the meter

UC Berkeley Wireless AC Meter (ACme)

- Wireless power meter for each device
- Mesh networking with backhaul over internet



UCB Early Demonstration



Meter & Network Development Team

- LBNL EETD
 - Field metering experience
 - Energy study design
- UC Berkeley EECS
 - Wireless sensor networks
 - Prototype ACme meters & network

New Meters

- Redesigned to improve safety, accuracy, reliability
 - Meters tested and approved for use by LBNL EH&S
- Report power, apparent power, energy every 10s
- 15A, 120V AC
- 0.4W idle power
- \$85 per calibrated unit.



New Meters

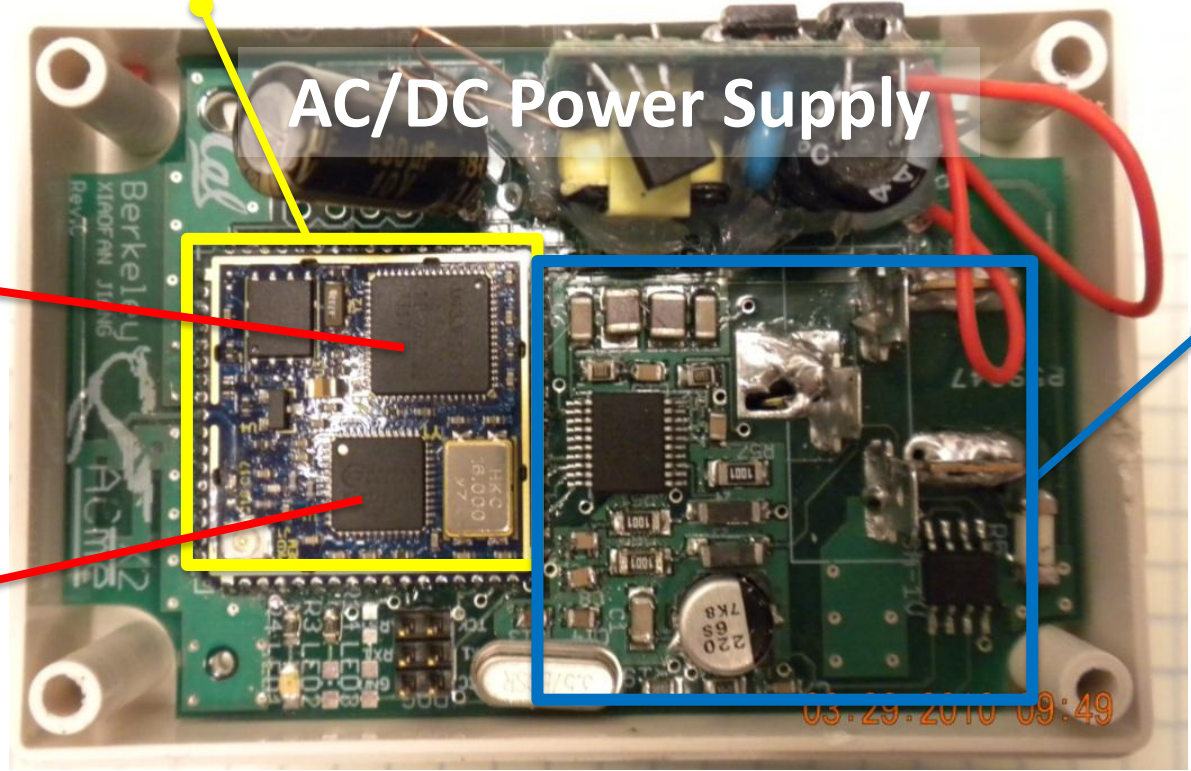
EPIC WSN Module

AC/DC Power Supply

Micro-processor

IEEE
802.15.4
Radio

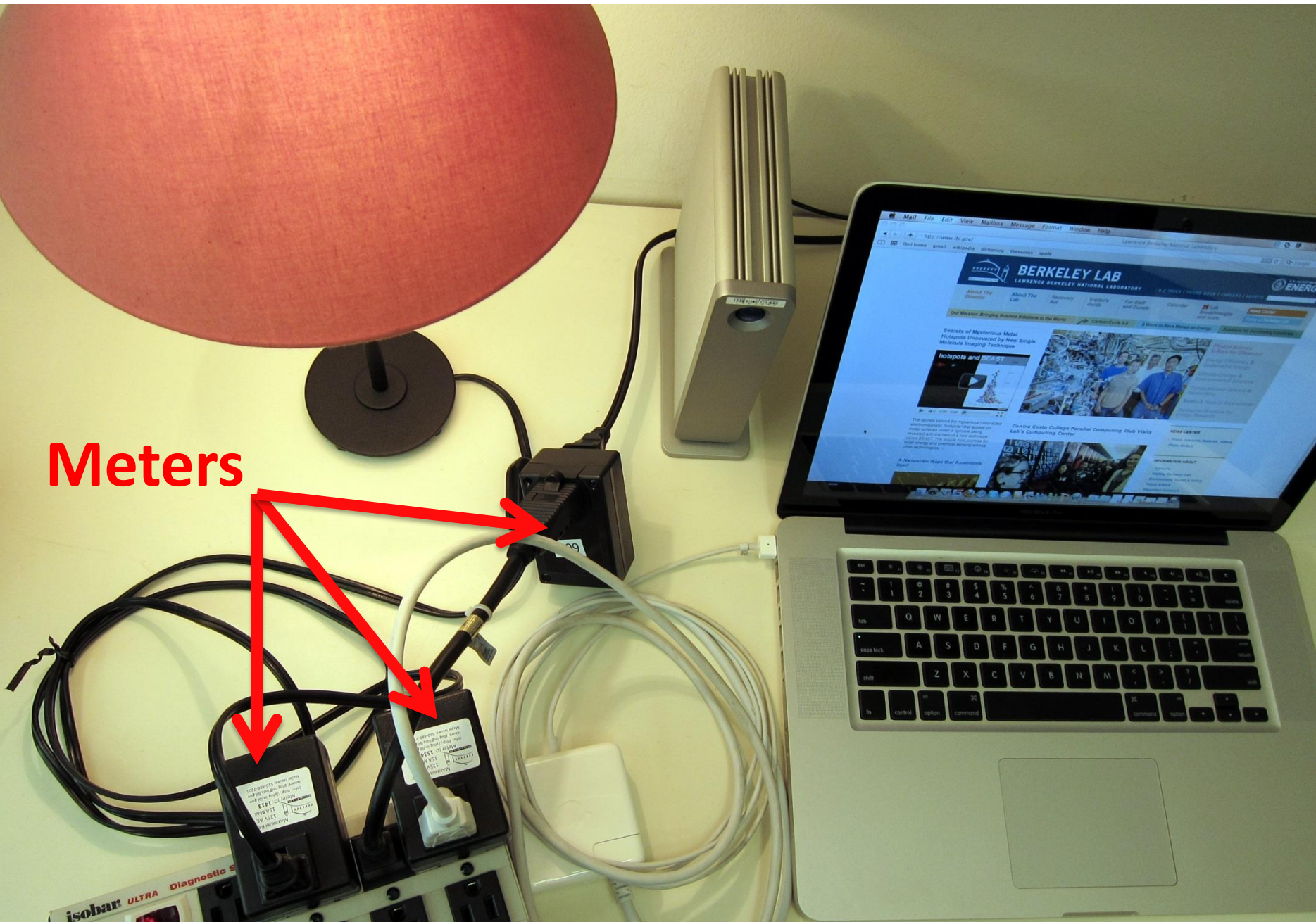
AC Power
Sensor



Project Overview & Methodological Findings:

Goals Field Sites Taxonomy & Inventory **Meter Development** Network Deployment

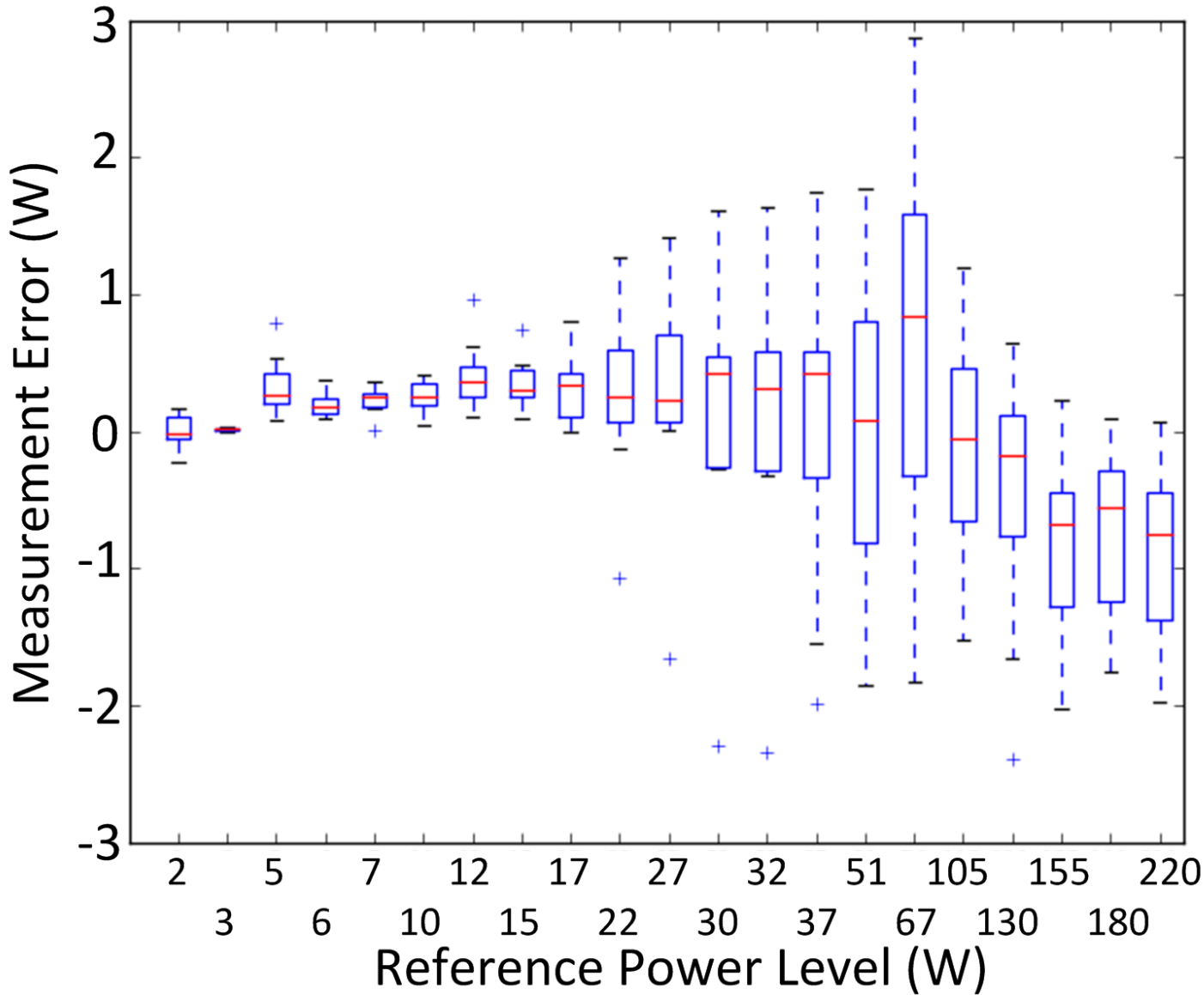
Meters



Meter Calibration

- Automated calibration
 - Five meters calibrated simultaneously
 - Computer controlled load switching, data collection, and calibration-constant calculation, and meter programming
 - 3 segment, piece-wise linear, least-squared error fit
- Each meter calibrated against 21 different loads
 - Resistive loads, 1W – 220W
 - 2 minutes per calibrated meter
- Considered a variety of load types & power levels

Example Meter Accuracy



B90 Device Sampling

- Staged by floor/division
- Stratified by device category
 - Sample weights set by expected energy use
- 9% of building devices metered
 - More electronics
 - More high users (e.g. water coolers, microwaves, etc.)

B90 Sampling Results

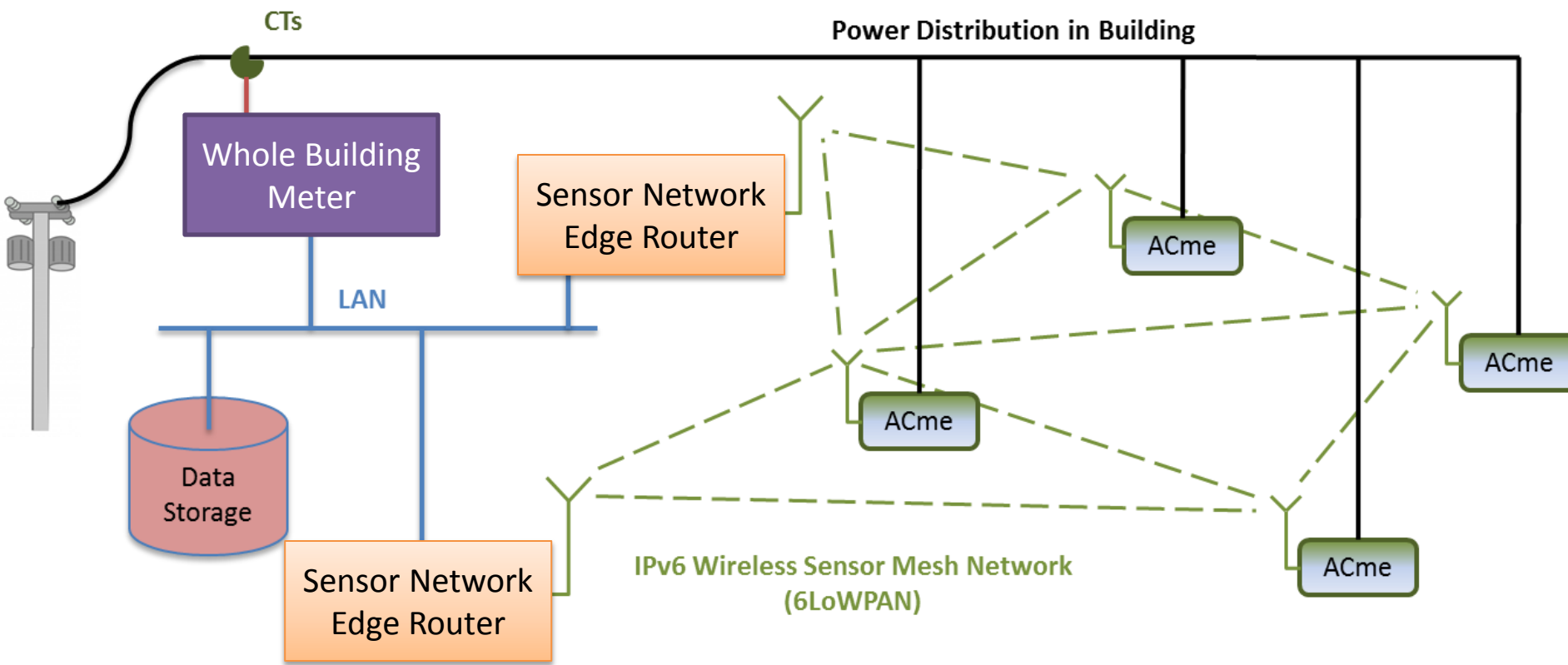
Electronics Categories	Count
Audio	1
Computer	118
Display	122
Imaging	63
Networking	20
Peripherals	26
Telephony	9
Video	3

Misc. Categories	Count
Business Equipment	6
Kitchen Equipment	8
Electric Housewares	17
Misc. HVAC	16
Misc. Lighting	35

Traditional Categories	Count
Traditional Appliance	11

455 meters deployed in B90

B90 Network Schematic



Project Overview & Methodological Findings:

Goals

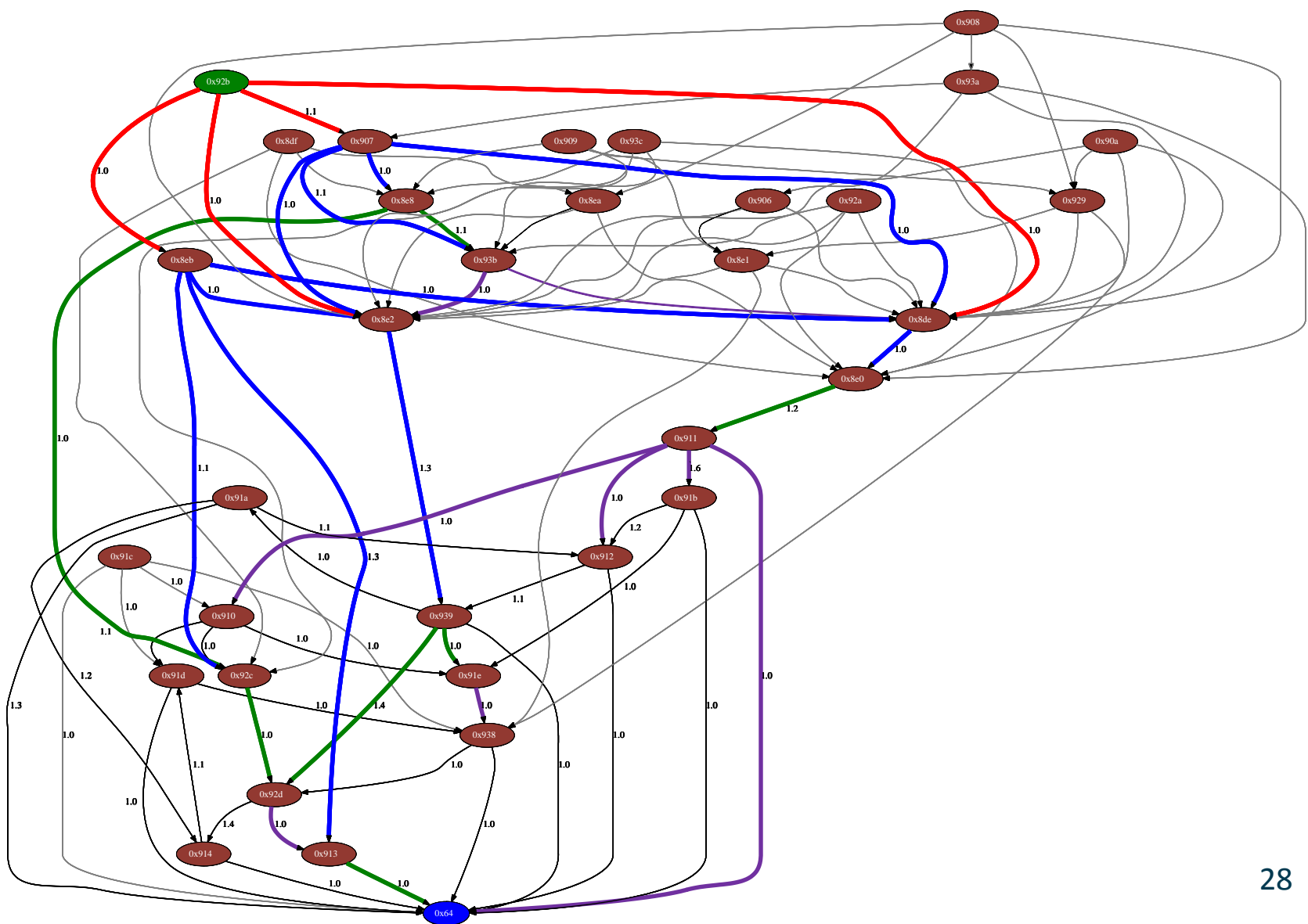
Field Sites

Taxonomy & Inventory

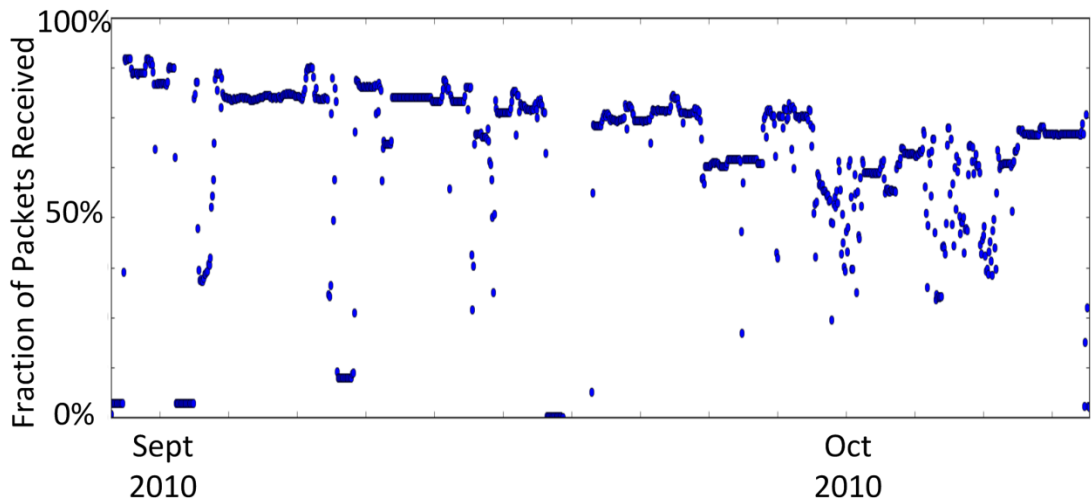
Meter Development

Network Deployment

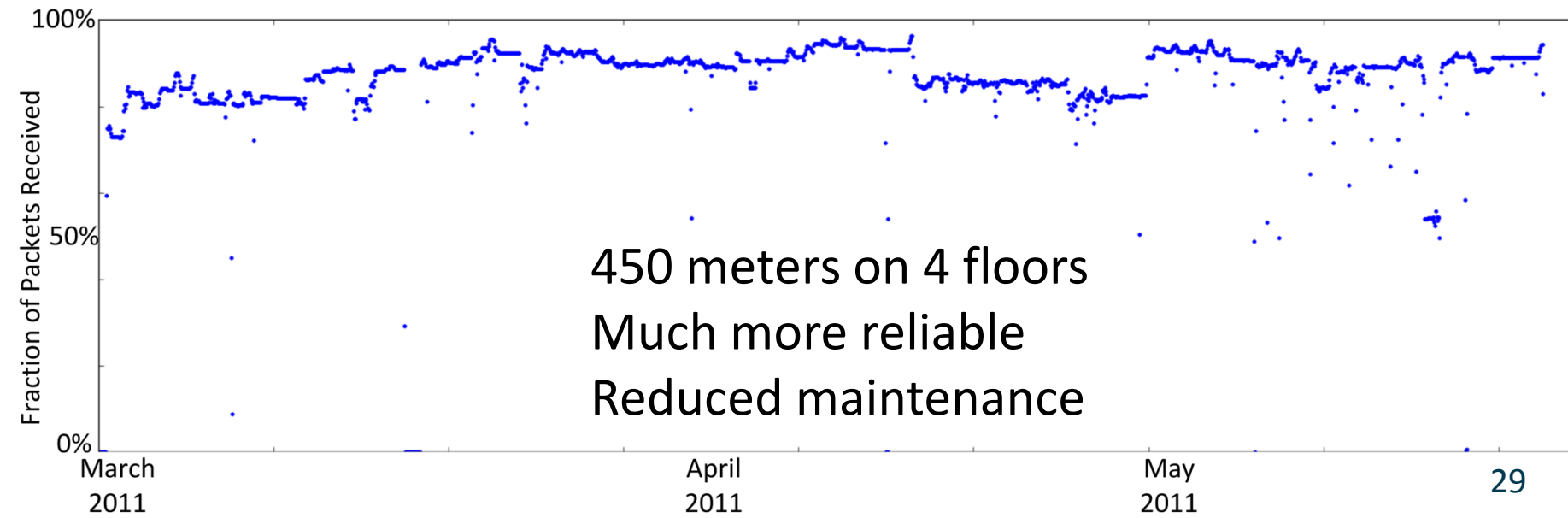
19-Node Network Connectivity Graph



B90 Network Reliability



100 meters on 1 floor
Lots of drop outs
High maintenance costs



450 meters on 4 floors
Much more reliable
Reduced maintenance

Ongoing Data Collection

- Houses installed in November, January
- B90 completed in February
- 960,000,000 rows in database
- 3,900,000 new rows in database every day

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- **Example Energy Data Analyses**
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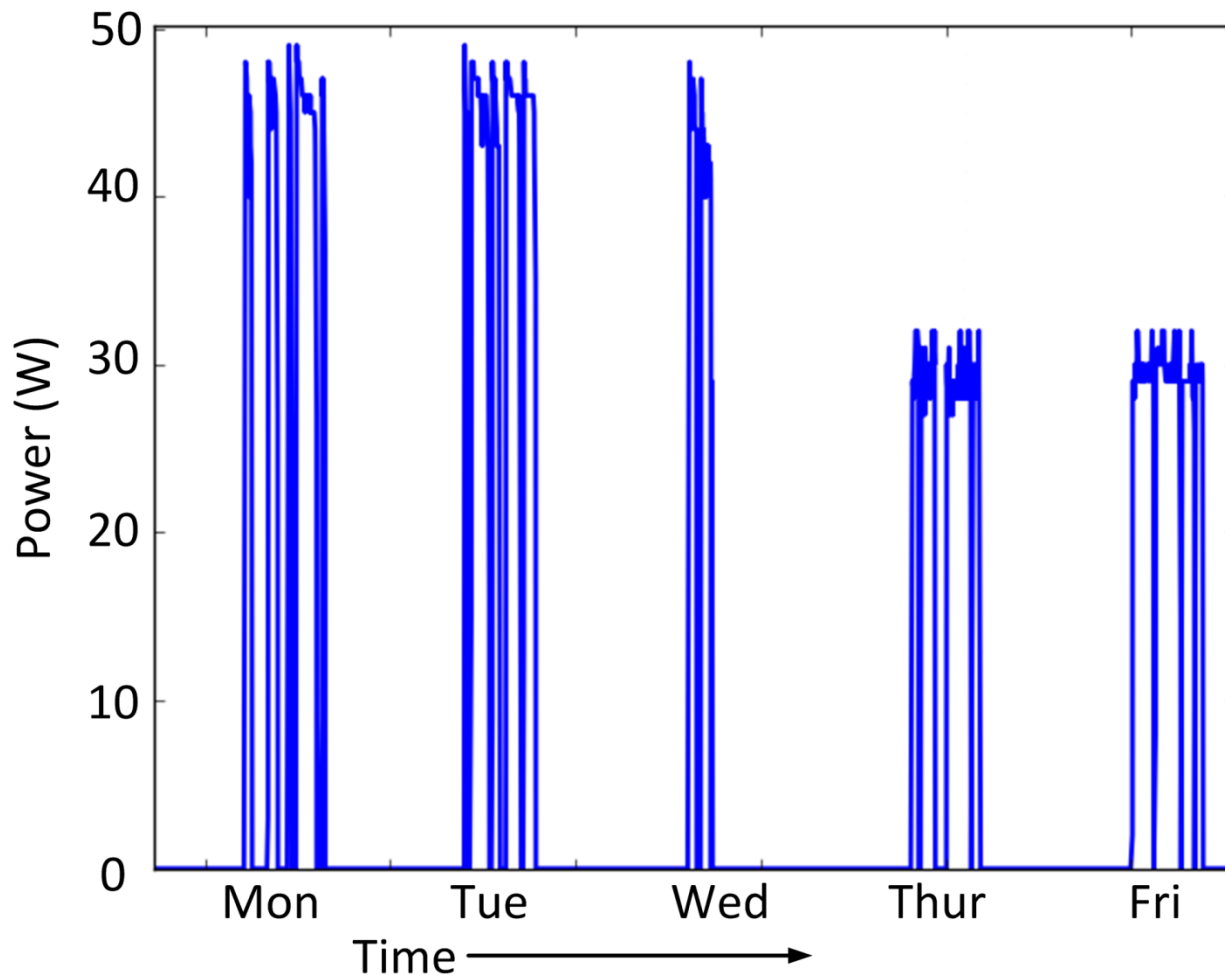
Data into Information

- Metering at building scale: lots of data
- Automated analysis to extract information
- Fill gaps in knowledge:
 - Whole building energy comparisons
 - Device utilization
 - Power management enabling rates
- Reveal energy saving opportunities

The following results are preliminary.

Inventory & Analysis Issues

- Building inventories change with time

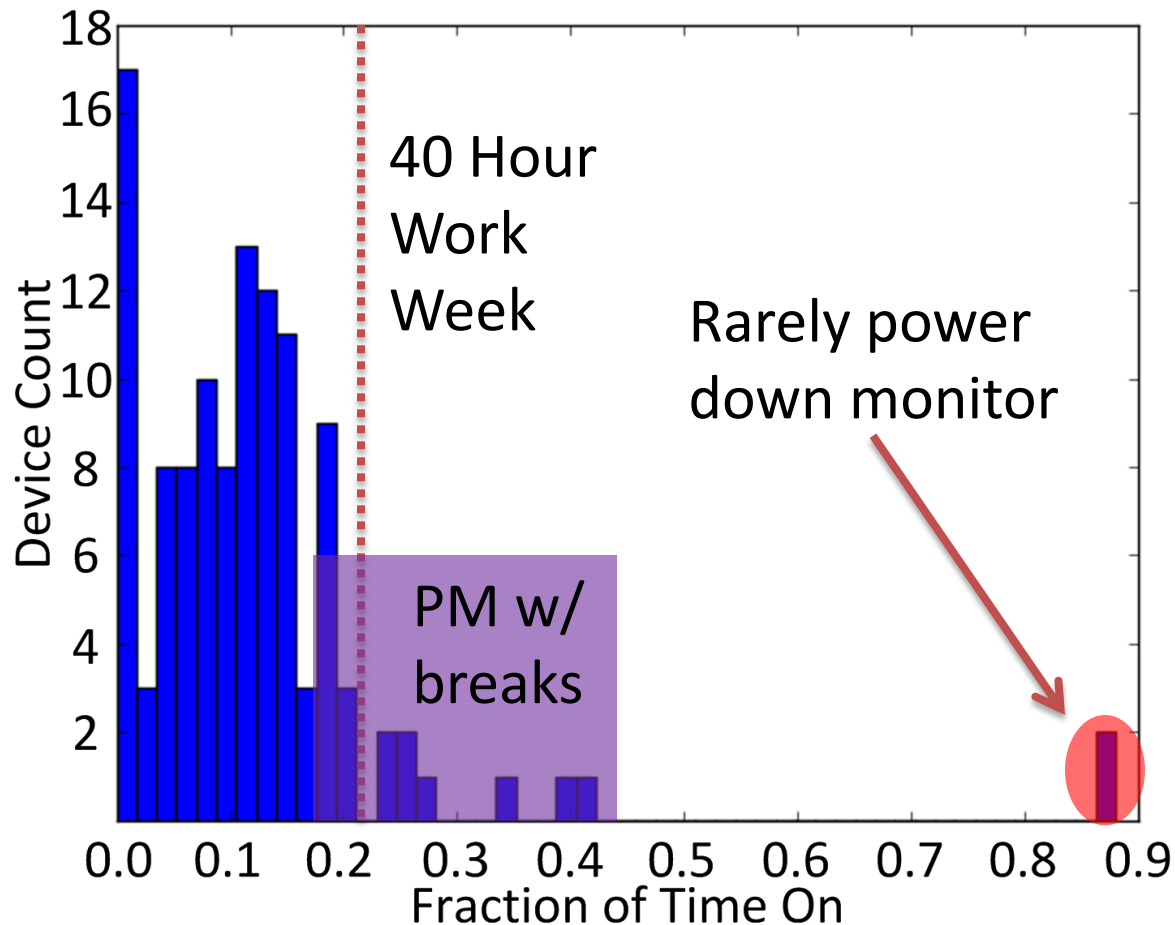


Change from
older 20" LCD to
new 24" LCD

Increase screen area
44%.

Reduce energy 33%.

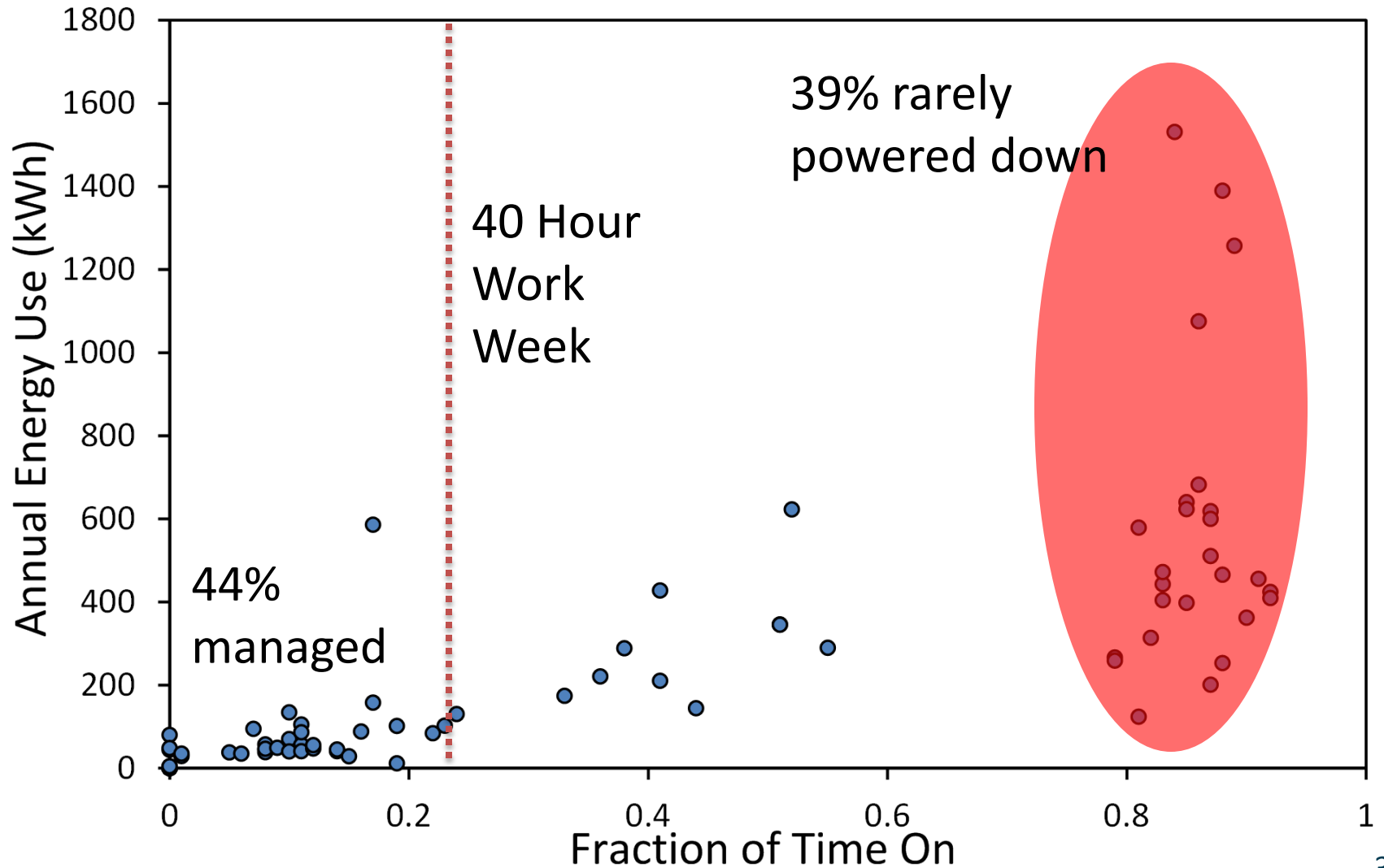
Computer Display Power Management



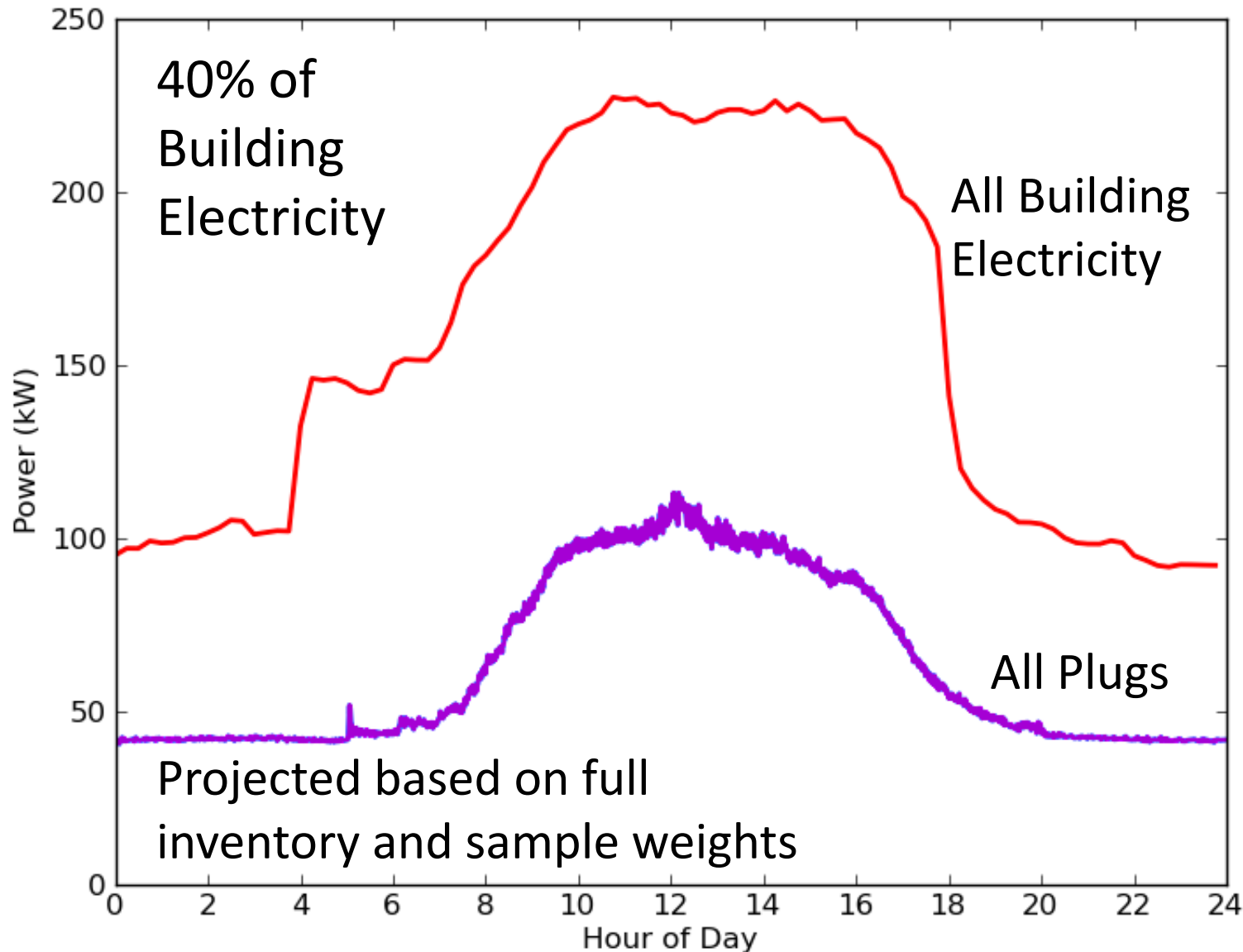
- 83% of monitors use power management
- 15% use it with breaks for days at a time
- 2% do not use it



Desktop Computers



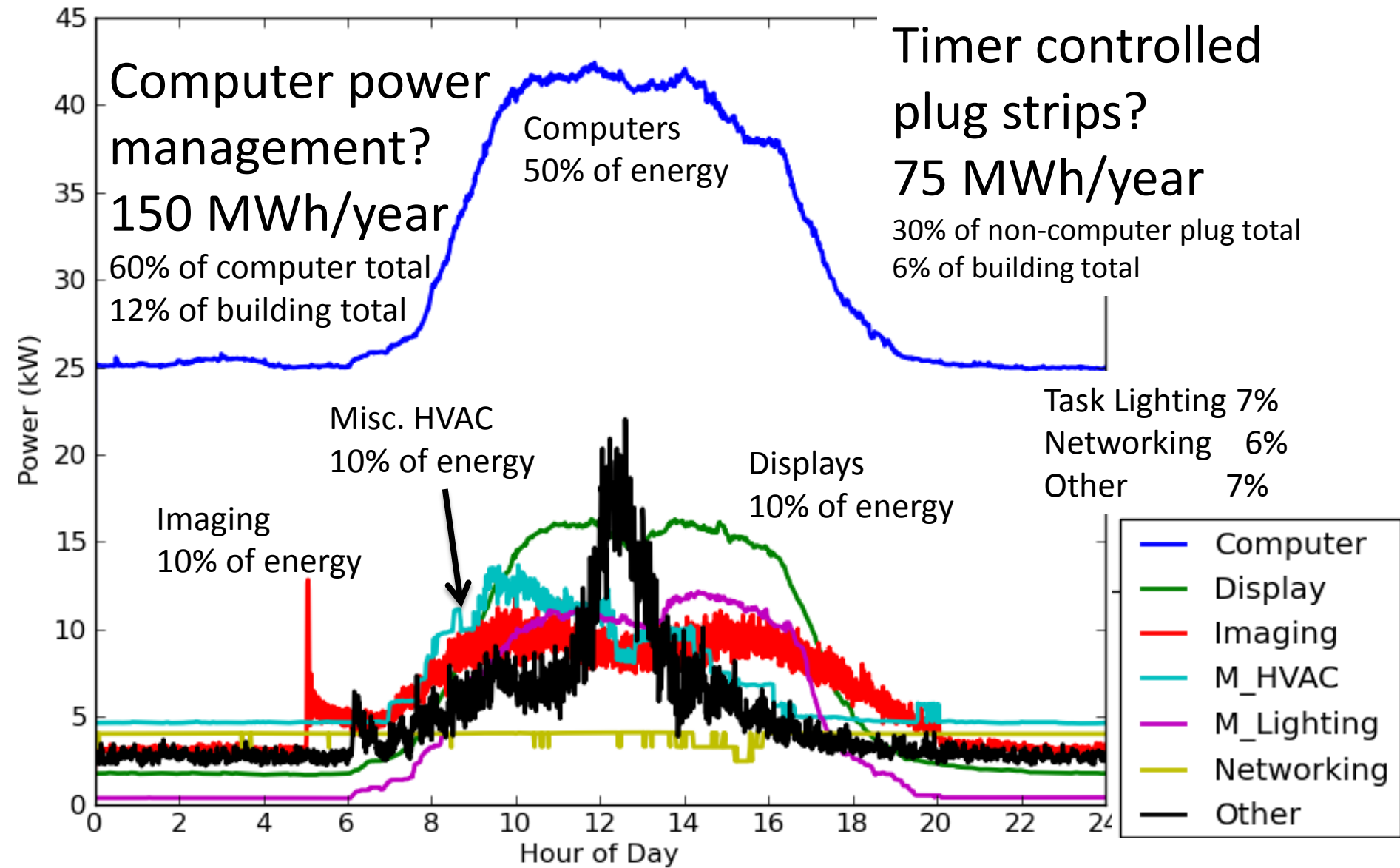
B90 Whole Building vs. Plugs



3 month
weekday
average:
March,
April,
May

Note: no cooling
during these
months

Breakdown of B90 Plugs



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Near Term Next Steps

- Expansion of data analysis
- Distill methodological findings
- Investigate energy savings potentials

Future Directions

- Wireless metering of gas and water at the end-use
- Roll metering out to DOE Building America
- Verifying persistent energy savings in buildings
- Smart devices: controls integrated into devices
- Connecting it all to make smart infrastructure

Acknowledgements

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Alan Meier

Wrap Up

- Demonstrated end-to-end metering system development
- Wireless embedded systems go beyond plug-in devices and data collection
 - Electronics for “smart” devices & buildings
 - Communications for controls & reporting
 - The networked building...

Information & Communications
Technologies have
changed the world

Imagine what
we can do with ICT
for energy efficiency.